ISRAEL JOURNAL OF ENTOMOLOGY, Vol. 48 (2), pp. 209–226 (14 November 2018)

This contribution is dedicated
to the memory of Prof. Dan Gerling,
a scientist, a colleague and a friend

REVIEW

Forty years of biological control in Mediterranean tomato greenhouses: The story of success

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ABSTRACT

The article highlights major landmarks in the development of Integrated Pest Management (IPM) programmes for tomato greenhouses in the Mediterranean region. This is the story of how biological control has been succesfully implemented as a cornerstone of IPM programmes in Catalonia (Northeastern Spain), one of the pioneering areas in the Mediterranean basin for the implementation of biological control in greenhouses. In the 1970s, *Trialeurodes vaporariorum* (Hemiptera: Aleyrodidae) was the key pest in the area and first programmes in protected tomato crops were based on inoculative releases of the parasitoid *Encarsia formosa* (Hymenoptera: Aphelinidae). However, failures caused by the expansion of *Encarsia pergandiella* (Hymenoptera: Aphelinidae) and the increasing importance of *Bemisia tabaci* (Hemiptera: Aleyrodidae) propitiated the change to use heteropterans of the Miridae family as biocontrol agents. These generalist predators were already observed during the first trials in the 1970s, but their use was not widespread until *B. tabaci* and the South American tomato pinworm *Tuta absoluta* (Lepidoptera: Gelechiidae) became serious problems. Despite scepticism of many IPM practitioners about the usefulness of these generalist natural enemies, mirid predators are currently widely used for protecting Mediterranean tomato crops. Papers on the biology, behaviour and ecology of the Miridae have gained importance in the scientific literature published over the last 35, which undoubtedly has promoted their inclusion in IPM programmes. The activities of the IOBC/WPRS Working Group "Integrated Control in Protected Crops, Mediterranean Climate" has had a major impact on the progress of biological control strategies in Mediterranean tomato greenhouses over last decades.

KEYWORDS: Biological control, generalist predators, parasitoids, whiteflies, tomato, Mediterranean, greenhouse farming.

RESUMEN

El artículo destaca los principales hitos en el desarrollo de los programas de Gestión Integrado de Plagas (GIP) del tomate de invernadero en la región me-

DOI: 10.5281/zenodo.1486574; ISSN (online) 2224-6304
urn:lsid:zoobank.org:pub:F764F0C3-0FB6-41A5-8417-0F0564EA3EC4

diterránea. Es la historia de cómo el control biológico se ha implementado de forma exitosa como parte fundamental de los programas GIP en Cataluña (noreste de España), una de las áreas de la cuenca mediterránea pioneras en la implementación del control biológico en invernaderos. En la década de 1970, *Trialeurodes vaporariorum* (Hemiptera: Aleyrodidae) era la plaga más importante en la zona y los primeros programas en tomate protegido se basaron en las liberaciones inoculativas del parasitoide *Encarsia formosa* (Hymenoptera: Aphelinidae). Sin embargo, los fallos causados por la expansión de *Encarsia pergandiella* (Hymenoptera: Aphelinidae) y la creciente importancia de *Bemisia tabaci* (Hemiptera: Aleyrodidae) propiciaron el cambio al uso de heterópteros de la familia Miridae como agentes de control biológico. Estos depredadores generalistas ya se habían observado en los primeros ensayos realizados durante la década de los 70, pero su uso no se extendió hasta que *B. tabaci* y la polilla del tomate *Tuta absoluta* (Lepidoptera: Gelechiidae) no se convirtieron en problemas importantes para el cultivo. A pesar del escepticismo de muchos especialistas en GIP sobre la utilidad de estos enemigos naturales generalistas, en la actualidad son agentes de control biológico ampliamente utilizados en los cultivos de tomate en el mediterráneo. Los artículos científicos sobre la biología, comportamiento y ecología de estos depredadores han ganado importancia en la literatura científica producida en los últimos 35 años, lo que sin duda ha facilitado su inclusión en los programas de GIP. Las actividades del Grupo de Trabajo de la IOBC/WPRS "Control Integrado en Cultivos Protegidos, Clima Mediterráneo" han tenido un gran impacto en el progreso de las estrategias de control biológico en los invernaderos mediterráneos de tomate en las últimas décadas.

PALABRAS CLAVE: Control biológico, depredadores generalistas, parasitoides, moscas blancas, tomate, mediterráneo, cultivo en invernadero.

INTRODUCTION

Greenhouse crops are of great importance in the agriculture of many Mediterranean countries. They represent very intensive farming systems that involve high amount of inputs. Quality of production, including cosmetic appearance, is a top priority in greenhouse crops and, therefore, much care has to be devoted to pest and disease management (Gullino *et al.* 1999). In the Mediterranean region due to the hot, dry summers and mild winters, vegetable crops are grown all year round both outdoors and mostly in unheated plastic greenhouses. Vegetable production coexists with ornamental crops, either in open field or in heated greenhouses, and can be done on small family-operated farms assisted or not by pest advisors, or by big companies under common technical guidelines. Under this situation, pests reproduce all year round with a continuous carry-over of insects among different crops and environments (Alomar *et al.* 1987; Gullino *et al.* 1999).

For many years the use of pesticides has been an affordable and simple way of protecting greenhouse high value crops. However, reducing the dependence on pesticides without reducing competitiveness has been an important goal in European agriculture in general and in greenhouse crops in particular. Several stimuli forced protected greenhouse growers to move to biological control strategies: the increasing demand by European consumers of more environmentally friendly farming products; the need to properly implement pesticide resistance management strategies; the existence of pests and diseases that are difficult to control with authorized active ingredients; the cut down in the number of registered active ingredients as insecticides; and the proliferation of European and National legislative initiatives to promote sustainable alternatives to the use of pesticides. Biological control has proved to be a reliable alternative to solve some of these challenges, especially in a scenario marked by increasing globalization and the climate change, that intensify the problem of invasive pests.

Our paper aims to review the long way travelled to develop biological control strategies in Mediterranean greenhouses and shows the changes occurred in the main techniques due to the active research in the domain and the innovative character of both field technicians and growers. To do that:

(1) we set a context on the world-wide research on biological control in greenhouse crops by analyzing trends of peer-reviewed papers mentioning key pests and natural enemies;

(2) as a case study, we describe the development of biological control based IPM in tomato greenhouses in the Mediterranean basin based on our experience in Catalonia (Northeast of Spain);

(3) we highlight the key contribution of the IOBC/WPRS Working Group "Integrated Control in Protected Crops, Mediterranean Climate" to this development.

The paper focuses on tomato since this is, by far, the most important crop in the area and the one in which the implementation of biological control in protected crops started.

PREVALENCE OF PESTS AND NATURAL ENEMIES IN THE WORLDWIDE SCIENTIFIC LITERATURE DEALING WITH GREENHOUSE CROPS (1981–2015)

To analyze the worldwide context regarding biological control in greenhouse crops we searched "All databases" of the Web of Science (WoS; Clarivate Analytics, https://clarivate.com/products/web-of-science) for papers published during 1981–2015. We performed two different searches, one for pests and one for natural enemies. The keywords/phrases used were whitefl*, spider mite*, thrip*, *Tuta*, aphid*, Leafmine*, non-tuta lepidopter* for arthropod pests; and whitefly parasit*, *Phytoseiulus persimilis*, aphid natural enem*, leafminer parasite*, thrips predat*, generalist mirid bug* for natural enemies. All these keywords were crossed with (greenhous* OR glasshous*) to refine those records to protected crops.

The changes in the number of references recorded in the WoS on pests and natural enemies in the world from 1981 to 2015 are reflected in Figures 1 and 2.

Insect and mite pests of greenhouse crops received an increasing attention from researchers throughout this period, but at different rates. Whiteflies, aphids and Lepidoptera other than *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) were the prevalent pest groups from 1991–1995 onwards. Thrips and spider mites constituted a second group of addressed pests, with a number of records that continuously increased from the period 1986–1990 onwards. Finally, leafminers were scarcely mentioned in the scientific literature along this period, and *T. absoluta* was only present in significant numbers in the last five years, after its introduction in Europe and its rapid distribution over the Mediterranean basin, Asia and Africa (Urbaneja *et al.* 2007; Campos *et al.* 2017). In general, the relative weight of each pest group in the scientific literature produced within this period did not change. Only references to Lepidoptera other than *T. absoluta* gained a relative weight in the last 10 years.

In contrast to the evolution of research interests on pests (Fig. 1), significant changes can be observed in the number of records regarding natural enemies (Fig. 2). The number of published papers dealing with the two most classical natural enemies used in greenhouse crops, whitefly parasitoids and *Phytoseilus persimilis* Athias-Henriot (Acari: Phytoseiidae), did not increase since mid-1990s and even slightly decreased during the last years, especially in the case of *P. persimilis*. On the contrary, the number of references increased significantly during the last 15–20 years for generalist mirid bugs (Hemiptera: Miridae) and thrips predators, mostly *Orius* spp. (Hemiptera: Anthocoridae) and predatory mites of the Phytoseiidae family, being the prevalent natural enemy groups over the last five years. Besides thrips, *Orius* spp. and predatory mites have been also investigated and used for the biological control of other arthropod pests such as whiteflies and mites of the eriophyoid and tarsonemid groups. Native generalist mirid bugs are prevalent in Mediterranean greenhouses to control several pests, including whiteflies, *T. absoluta*, leafminers and spider mites, and are commonly used in augmentative and conservative biological control strategies.

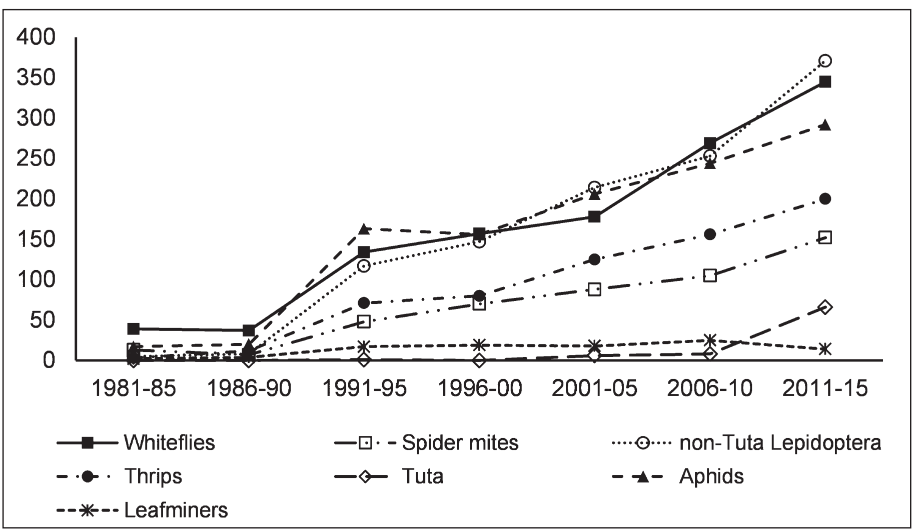

Fig. 1: Number of references per five-year intervals that refer to the insect and mite pests of greenhouse crops as recorded in the WoS (1981–2015).

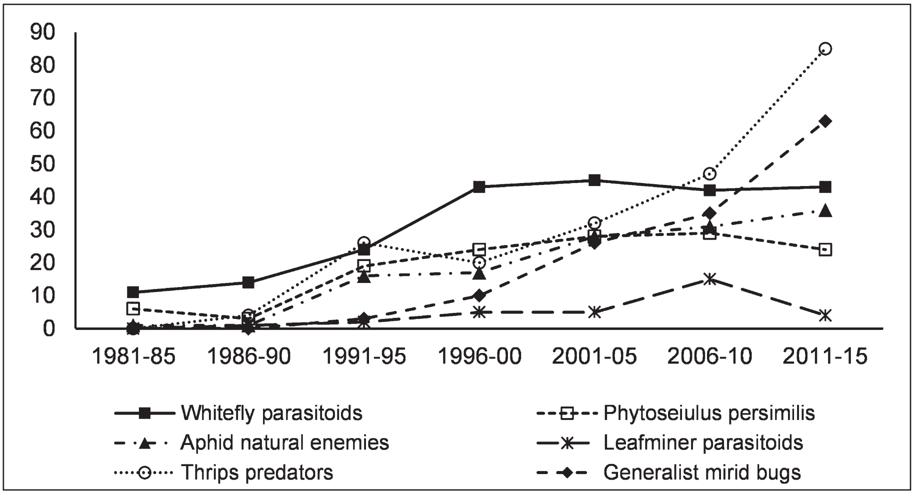

Fig. 2: Number of references per five-year intervals that refer to natural enemies of greenhouse crops as recorded in the WoS (1981–2015).

In summary, whereas the relative importance of records dealing with insect and mite pests in protected crops has not significantly changed in the last 35 years, the type of natural enemies investigated and commercially used has changed considerably with a shift towards the use of generalist predators, like predatory mirids, anthocorid bugs and phytoseiid mites. The same trend has been observed in the implementation of IPM programmes based on biological control in greenhouse tomatoes.

DEVELOPMENT OF BIOLOGICAL CONTROL IN MEDITERRANEAN GREENHOUSE TOMATOES

In the Mediterranean basin, biological control of tomato pests has been developing across the years following two different strategies: the first one based on the use of parasitoids targeting the greenhouse whitefly *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae), and the other one based on the use of polyphagous predators to control the tobacco whitefly *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) and the South American tomato pinworm *T. absoluta*. Other pests have not been considered as key agents in greenhouse tomatoes (see the following section on IOBC contribution for details).

In Spain, biological control in greenhouse vegetables started in Catalonia (NE Spain) (Casadevall *et al.* 1979), one of the pioneering areas in the Mediterranean basin for the implementation of biological control in greenhouses. Following works in the United Kingdom and the Netherlands, first experiments on biological control of the greenhouse whitefly *T. vaporariorum* were conducted with the parasitoid *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae). The use of the parasitoid, together with cultural practices was implemented as an IPM package for commercial spring tomato greenhouses from late 1980s onwards. This programme contributed to breaking the carry-over of whitefly populations over the year (Alomar *et al.* 1987). Similar plans were experimentally used in other Mediterranean countries like France, Italy and Greece, and seminal results were discussed at several European Expert's Group Meetings (Cavalloro 1987; Cavalloro & Pelerents 1989).

The native *Encarsia tricolor* Foërster (Hymenoptera: Aphelinidae), the commonest whitefly parasitoid in the area, was included in the initial experiments as a potential biological control agent (Albajes *et al.* 1980; Onillon *et al.* 1987). However, the development of commercial insectaries in Europe, where *E. formosa* was mass produced (Onillon 1990), resulted in a significant increase of greenhouse crops managed with the latter parasitoid, and the field studies on *E. tricolor* were abandoned.

Together with releases of *E. formosa* for whitefly control, the programme also included augmentations of *Diglyphus isaea* (Walker) (Hymenoptera: Eulophidae), the native parasitoid of leafminers belonging to the genus *Liriomyza* Mik (Diptera: Agromyzidae), the conservation of aphid native natural enemies, and the application of suitable cultural practices (Albajes *et al.* 1994). The programme was successful in controlling *T. vaporariorum.* Initial reliance on natural parasitism by *D. isaea* was enough to control *Liriomyza* spp. in most cases, and only 25% of the greenhouses needed supplementary releases of the parasitoid. Besides the native *L. bryoniae* (Kaltenbach), the exotic *L. trifolii* (Burgess) was also present in tomato crops since early 1980s causing very severe damage not only to vegetables but also to ornamental crops (Martin 1984; Casadevall *et al.* 1988). However, Albajes *et al.* (1994) reported a shift in species dominance from the invasive to native, probably due to a better control exerted by *D. isaea* on *L. trifolii* than on *L. bryoniae*. With regards to aphids or lepidopteran pests, the percentage of greenhouses where selective sprays were needed was very variable among seasons, but the proportion of crops requiring miticide treatments increased with years due to the detection and establishment of the tomato russet mite *Aculops lycopersici* (Massee) (Acari: Eriophyidae). Nowadays, biological control of this species is still under development and the effectiveness of new natural enemies is being investigated (van Houten *et al.* 2017).

The cooperation between research, pest control advisers (PCAs), and particularly the guidance of PCAs of the Growers Associations for Plant Protection (ADV by its Catalan acronym) were crucial to implement the programme at the farm level. Spanish and Catalan Governments facilitated and subsidized their creation with the aim to engage PCAs in the implementation of IPM programmes in several crops (Albajes *et al.* 2003). Overall, the programme succeeded in reducing the average number of insecticides to less than one per greenhouse and the number of fungicide sprays by 80%. The same plan was also implemented in the Balearic

Islands, the Basque Country and in Southeastern Spain (Albajes *et al.* 1994; Calvillo 1994; Arnó 1997).

In the early 1990s, an exotic whitefly parasitoid, *Encarsia pergandiella* Howard (Hymenoptera: Aphelinidae) imported in 1978 from USA to Italy (Viggiani & Mazzone 1980), naturalized and became widespread in Southeastern France and Northeastern Spain (Onillon *et al.* 1994; Videllet *et al.* 1997). By the late 1990s, *E. pergandiella* spontaneously outcompeted the released *E. formosa* preventing successful establishment of the latter. *Encarsia pergandiella* pupae were already found in 90% of the greenhouses in which *E. formosa* had been released, resulting in less than 40% whitefly parasitism rates, much lower than recorded in previous years (Gabarra *et al.* 1999). This was probably due to a higher tolerance of *E. pergandiella* to low temperatures and the hyperparasitic production of males on *E. formosa* pupae.

An important event in the development of biological control was the spread of *B. tabaci* and associated diseases caused by members of the *Tomato Yellow Leaf Curl Virus* (TYLC) group. Although already problematic in Israel and Turkey from the 1970s, *B. tabaci* was not considered a concerning pest in many Mediterranean countries (Gerling 1996). However in the 1990s, both whiteflies—*T. vaporariorum* and *B. tabaci*—coexisted in greenhouses of the warm-temperate area, while only the latter species was present in greenhouses of the warmer region further south, causing severe TYLC disease problems (Gabarra & Besri 1999). Releases of *E. formosa* did not provide an adequate control and, under that scenario, several attempts of using *Eretmocerus* spp. (Hymenoptera: Aphelinidae) were conducted (Gerling *et al.* 2001). The native *Eretmocerus mundus* Mercet is very common in the Mediterranean and does not parasitize *T. vaporariorum* (Gerling *et al.* 1980), while the exotic *E. eremicus* Rose & Zolnerowich (= *E. californicus* Howard) attacks both *B. tabaci* and *T. vaporariorum* and provides control for mixed host populations (Gerling *et al.* 2001). Different commercial companies released *E. eremicus*, native to the Southwestern USA, in Spanish and other European greenhouses. Natural-enemies producers preferred this species to the native *E. mundus* because *E. eremicus* could be produced and sold on *T. vaporariorum*, whereas *E. mundus* could only be mass reared on *B. tabaci*, a quarantine pest in Central and Northern Europe. However, *E. eremicus* was not very successful because it was often replaced by naturally occurring *E. mundus* (Gerling *et al.* 2001; Arnó *et al.* 2010*b*; Stansly & Natwick 2010).

The failure in the use of the released parasitoids propitiated the change to use generalist predators. On one hand, the expansion of *B. tabaci* and *E. pergandiella* made releases of *E. formosa* useless. On the other hand, *E. mundus* was not a realistic alternative for commercial companies to produce, and the exotic *E. eremicus* did not establish well in Mediterranean tomato crops. Simultaneously to this gap in the availability of effective parasitoids, there was an increasing awareness of the potential shown by polyphagous predators such as mirid bugs as biological control agents (Albajes & Alomar 1999). Predatory mirid bugs were reported as the most abundant and effective natural enemies for controlling *T. vaporariorum* on tomato crops (Gabarra & Besri 1999) and were able to prey on other important tomato pests such as *B. tabaci*, aphids and leafminers (Alvarado *et al.* 1997; Barnadas *et al.* 1998; Arnó *et al.* 2003).

The presence of mirids was already observed during first trials with *E. formosa* in Catalonia (Casadevall *et al.* 1979; Albajes *et al.* 1980) and in other areas (Carnero *et al.* 1987; Fauvel *et al.* 1987). Those studies mentioned species from the genera *Macrolophus* Fieber, *Dicyphus* Fieber and *Nesidiocoris* Kirkaldy. For many years, two *Macrolophus* species, *M. caliginosus* (Wagner) and *M. pygmaeus* (Rambur) (Hemiptera: Miridae) were mentioned as key predators of several pests in vegetables. Works by Perdikis *et al.* (2003), Martínez-Cascales *et al.* (2006) and Castañé *et al.* (2013), who combined classical taxonomy with molecular methods, showed that the correct name of the species used as biocontrol agent in tomato is *M. pygmaeus*, to which all citations of the natural enemy used on this crop should be ascribed.

Many IPM practitioners were sceptical about the use of generalist predators since unlike conventional biological control programs based on specific parasitoids, there was no univocal correspondence between the target prey and the beneficial. In fact, the first inoculations of *M. pygmaeus* were made to complement the control provided by *E. formosa*. Parasitoid releases ensured initial whitefly control while the predator populations did establish in the crop (Malézieux *et al.* 1995; Gabarra & Besri 1999; Castañé *et al.* 2000). Over time, polyphagy has been considered an advantage because it allows the control of more than one pest and different pest stages with the same natural enemy, avoiding the need of releasing multiple natural enemies. It also allows the early establishment of the predator in the crop when the target pest is still at low densities, and helps to maintain a resident population of the natural enemy when biological control of the target prey has been achieved (Albajes & Alomar 1999; Castañé *et al.* 2016). These characteristics have generalized the use of these polyphagous predators in Mediterranean greenhouses despite being zoophytophagous, that is to say, they not only feed on animal prey, but also on plant resources. Under specific circumstances, plant-feeding by predatory mirids may damage the tomato plant. This damage may vary depending on pest abundance, plant stage, plant nutrition, variety, crop cycle, weather conditions, etc. (Castañe *et al.* 2011). Albajes *et al.* (2006) provide guidance as to how to assess the risk of damage.

Two of these mirid species, *M. pygmaeus* (sold during many years as *M. caliginosus*) and *N. tenuis* (Reuter), have been mass reared and sold by many companies. Both species became the key element of several biological control programmes on tomato and are still in use. *Macrolophus pygmaeus* was the first species of predatory mirid bug released in tomato crops. In fact, as early as late 1980s it was already considered as a potential candidate to be inoculated in greenhouses (Malausa *et al.* 1987). Over time, its use became so successful that some growers' associations also developed their own local rearings to supply their farmers with these predators. That is the case, for example, of *Savéol* in France and *Selmar* in Spain. Nowadays, it is a preferred natural enemy to be used in tomato crops in Northeastern Spain and in France, and there is a growing interest in its conservation through different tomato crop cycles around the year. With this goal, many farms establish flower strips of *Calendula officinalis* L. (Asteraceae) inside and outside the greenhouse to serve as a refuge for these predators during crop-free periods (Castañé *et al.* 2016).

Nesidiocoris tenuis has been released in tomato greenhouses in warm parts of the Mediterranean region like Southern Spain (van der Blom *et al.* 2009), while in other parts of Europe the bug is considered too risky (Pérez-Hedo & Urbaneja 2016). Feeding on the plant by this zoophytophagous predator results in necrotic rings on the stem, shoots, leaf petioles and flower stalks, and adversely affects both the plant growth and crop yield (Sanchez & Lacasa 2008; Arnó *et al.* 2010*a*). Preplant releases of the predator when seedlings are still in the nurseries have been promoted as a way to accelerate its establishment and improve pest control of *B. tabaci* and *T. absoluta* (Calvo *et al.* 2012*a*, *b*; Pérez-Hedo *et al.* 2017). This early establishment of *N. tenuis* increases its efficacy, especially when transplants occur during summer with high pest pressure, and harvest extends to the next spring. In spite of the success obtained with that strategy, the risk of damage in some cases is not negligible. Since *N. tenuis* is very well adapted to warm conditions, high natural populations may develop over time in the area where releases are done, thus increasing the risk of damage in other crop cycles and in some varieties. Aiming at developing new systems to regulate *N. tenuis* populations and make their management more sustainable some plants as *Dittrichia viscosa* L. (Asteraceae) and *Sesamum indicum* (L.) (Pedaliaceae) have been proposed as banker or trap plants (Cano *et al.* 2009; Biondi *et al.* 2016).

Other mirid species have also been recorded on tomato crops in the Mediterranean. *Dicyphus errans* Wolff has been mainly found in northern Mediterranean Basin (Ingengo *et al.* 2009). Another species, identified as *Dicyphus tamaninii* Wagner, accounted for 80% of mirid bugs naturally occurring on tomato crops in Northeastern Spain (Gabarra *et al.* 1988; Alomar *et al.* 1991). Early in the 1990s, the development of a decision chart to successfully manage its natural populations in tomato crops (Alomar *et al.* 1991) provided a good example that the use of polyphagous predators and conservation strategies in both protected and field tomatoes was a realistic approach for biological control programmes in the Mediterranean (Albajes *et al.* 1996). However, its natural abundance decreased over time to only 26% in 1993–1994, and to just 10% in a survey conducted in open fields in 1999 (Castañé *et al.* 2000). Although being the first predatory mirid bug species for which a conservation biocontrol programme was developed in Spain, *D. tamaninii* has never been proposed for inoculative releases in tomato greenhouses.

Its use was considered too risky due to its zoophytophagy (Castañé *et al.* 2011). A recent review by Sanchez and Cassis (2018) indicates that sample material from our area actually belongs to *D. bolivari* Lindberg and not to *D. tamaninii*, and that both species can only be separated on slight differences in the male genitalia. Therefore, our published work on *D. tamaninii* should be probably referred to *D. bolivari*, as well as papers dealing with *D. maroccanus* Wagner (e.g. Abbas *et al.* 2014).

As it has been discussed up to now, the contribution of predatory mirid bugs to the biological control in Mediterranean tomato greenhouses is fundamental (Pérez-Hedo & Urbaneja 2016). Nevertheless, they are not the only natural enemies involved in the natural biological control of key pests as, for example, *T. absoluta*. This pest was first detected in Spain in 2006 (Urbaneja *et al.* 2007) and from there it spread over the Mediterranean area (Campos *et al.* 2017). The biological control of *T. absoluta* is based mainly on the use of mirid bugs that are very effective preying on the moth eggs (Arnó *et al.* 2009; Urbaneja *et al.* 2009, 2012). A wide complex of indigenous larval parasitoids have shifted to this new resource, *Necremnus tutae* (Ribes & Bernardo) (Hymenoptera: Eulophidae) being the most abundant and widespread (Ferracini *et al.* 2012; Urbaneja *et al.* 2012; Zappalà *et al.* 2012, 2013; Biondi *et al.* 2013; Gabarra *et al.* 2014; Gebiola *et al.* 2015). Natural populations of this parasitoid also have a significant contribution to *T. absoluta* control in Tunisia and Spain (Abbes *et al.* 2014; van der Blom *et al.* 2016).

The coexistence of several pests and natural enemies in Mediterranean tomato greenhouses results in complex food webs. The important development of molecular techniques based on the analysis of consumed DNA within predators has become an indispensable tool in crop protection and biological control studies. It has also been applied and contributed to solve problems in the development of IPM programmes that could not be resolved with traditional methods. The development of prey-specific molecular markers has allowed to determine and evaluate predation exerted by mirid bugs on tomato (Agustí *et al.* 1999, 2000). They also allowed the evaluation of the importance and the consequences of intraguild predation of polyphagous mirids bugs on their parasitoids (Moreno-Ripoll *et al.* 2012, 2014) and to assess plant and prey feeding by omnivorous mirids (Pumariño *et al.* 2011). Clearly, the use of Next Generation Sequencing (NGS), which does not require the design of specific markers, has its potential to highlight many hidden trophic interactions that may contribute to further fine-tune biological control programmes (Gomez-Polo *et al.* 2016).

THE IOBC/WPRS CONTRIBUTION

As attested by many above cited references, the research activity of the IOBC/WPRS Working Group "Integrated Control in Protected Crops, Mediterranean Climate" has had a major impact on the progress of biological control strategies in Mediterranean tomato greenhouses. The aim of the group is to promote research,

Table 1. Convenors, meetings and publications of the IOBC/WPRS Working Group "Integrated Control in Protected Crops, Mediterranean Climate".

Period	Convenor	Meetings	Bulletin
1983–1990	Prof. Alfio Nucifora University of Catania (Italy)	Italy (1984) Greece (1985) Spain (1987) France (1989)	Cavalloro 1987 Cavalloro & Pelerents 1989
1991–2000	Prof. Ramon Albajes University of Lleida (Spain)	Italy (1991) Portugal (1994) Spain (1997) Turkey (2000)	WPRS Bull. 1991/XIV/5 IOBC-WPRS Bull. 17(5) IOBC-WPRS Bull. 20 (4) IOBC-WPRS Bull. 23 (1)
2003–2012	Dr. Cristina Castañé IRTA (Spain)	Morocco (2003) Spain (2006) Greece (2009) Italy (2012)	IOBC-WPRS Bull. 26 (10) IOBC-WPRS Bull. 29 (4) IOBC-WPRS Bull. 49 IOBC-WPRS Bull. 80
2012–present	Prof. Carmelo Rapisarda University of Catania (Italy) Prof. Dan Gerling (deceased in 2016) Tel-Aviv University (Israel)	Israel (2015) Portugal (2018)	IOBC-WPRS Bull. 119 IOBC-WPRS Bull. (in press)

development, implementation and training of Integrated Pest and Disease Management systems in protected crops in Mediterranean conditions.

Kick-off of this group was forged in four Expert's Group Meetings promoted by the European Union that were held in Italy (Catania, 1984), Greece (Heraklion, 1985), Spain (Cabrils, 1987) and France (Antibes, 1989). Proceedings of two of these meetings were published (Cavalloro 1987; Cavalloro & Pelerents 1989). From then onwards, the group has met regularly every three years and published the IOBC/WPRS Bulletin with contributions from all participants (Table 1). The working group has served for bringing together people from the academia (including students), pest control advisers and technical personnel from the biocontrol industry, and others. Participants originate mainly from the Mediterranean area and other EU countries, but delegates from Africa, Americas and Asia also attend these meetings on a regular basis.

From 1991 to 2015, nine issues of the IOBC/WPRS Bulletins were produced, each amounting to around 265 pages on average. During these 26 years, a total of 171 contributions dealt with tomato greenhouse crops. The vast majority referred to arthropod pests (83 %), whereas only 17 % dealt with plant diseases, including plant parasitic nematodes. Among those addressing pests, there were contributions providing a general overview of tomato pests and the different solutions applied in a specific region or country. Arthropod pest biology, behaviour and damage was a key topic in many issues. Most of the contributions dealt with the biology and damage of whiteflies, mainly *B. tabaci* (*s.l.*) and *T. vaporariorum*, and from 2009 onwards with the biology and damage of the tomato borer *T. absoluta*, whereas only a few addressed other pests as dipteran leafminers (*Liriomyza* spp.) or spider mites. Sixty-two percent of the contributions focused on different non-chemical strategies for pest control, with specific emphasis on biological control, and on all different aspects of the implementation of this strategy. Parasitoid identification, biology and ecology, mainly for whitefly and to a lesser extent for *T. absoluta* control, was also a hot topic. Polyphagous predators (especially mirid bugs), their biology, efficacy in pest control (mainly for whiteflies and *T. absoluta*) and taxonomical identification were also significantly reflected in published articles. Strategies for mirid bug conservation and the simultaneous use of these predators and parasitoids, as well as biological control of whiteflies using entomopathogenic fungi, were tackled in several contributions. Other studies reported development of non-chemical methods as greenhouse netting to avoid or delay the entrance of pests, insect traps, and plant resistance to pests. Studies of disease management were much less addressed during the Working Group meetings and, consequently, in the Bulletin publications. General disease management of the crop, biological control with antagonistic fungi, different control strategies as soil solarization, nematodes, and climatic or nutrient management of the crop in order to reduce disease incidence were the topics addressed in decreasing number of contributions.

The group also served to coordinate efforts in the dissemination on IPM fundamentals and development through several international training courses and with the publication of a book edited by three IOBC/WPRS convenors (Albajes *et al.* 1999). Collaboration with other organizations also strengthened management of particularly harmful pests. This was exemplified by the "EPPO/IOBC/FAO/NEPPO Joint International Symposium on management of *Tuta absoluta*", held in Agadir, Morocco in 2011 (Zlof & Suffert 2012).

Prof. Dan Gerling was elected as convenor of the Working Group together with Prof. Carmelo Rapisarda at the 2012 meeting in Sicily (Italy), and both organized the last meeting in Rehovot (Israel, 2015). Prof. Gerling was an enthusiastic participant of the Group meetings from as early as 1991 in Alassio (Italy). Most of his contributions dealt with the whitefly *B. tabaci* and its parasitoids, but participants greatly appreciated his wide comprehensive vision of biological control in Mediterranean agroecosystems. Although his expertise focused primarily on whitefly parasitoids, he was always aware of the importance of predators in biological control (Gerling 1996; Gerling *et al*. 2001).

In conclusion, the implementation of biological control in Mediterranean greenhouse tomatoes has gone a long way from the inoculative use of exotic parasitoids to the conservation and augmentative strategies of natural enemies native to the Mediterranean basin. The biodiversity richness of this area has provided many candidates that were, and still are, used in tomato greenhouses (Nicoli & Burgio 1997). Since most of released natural enemies in the Mediterranean greenhouses are native to the Mediterranean, biological control not only benefits from inoculation of individuals reared in commercial insectaries, but also from the conservation of a wide guild of parasitoids and predators that together contribute to the success of biological control programmes. Probably a deeper understanding of the ecology of generalist predators, including thropic interactions at the landscape scale, would help to manage better their populations in conservation biological control and would lower the amount of beneficials to be released into greenhouse and outdoor vegetable crops.

ACKNOWLEDGEMENTS

We thank all the research projects awarded by the Spanish and Catalan Governments and the EU that during these years funded the research needed to build knowledge on biological control in Mediterranean climate and to develop IPM programmes. We are also indebted to PCAs and farmers that significantly contributed to the success of these programmes. All authors belong to institutions supported by CERCA Programme (Generalitat de Catalunya). We also thank the contribution of the two reviewers that helped us to improve the manuscript.

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